PRTD Conditioning Circuit and Temperature Controller

Preliminary

ADT70/ADT71*

FEATURES
- **PRTD Temperature Measurement Range**
- **Typically IC Measurement Error ±0.1°C**
- **Includes Two Matched Current Sources**
- **Rail-to-Rail Output Instrumentation Amp**
- **Uncommitted, Rail-to-Rail Output, Op Amp**
- **On-Board +2.5 V Reference (ADT70)**
- **Temperature Coefficient ±15 ppm/°C**
- **+5 V or ±5 V Operation**
- **Supply Current 3 mA max**
- **10 µA max in Shutdown**

APPLICATIONS
- **Temperature Controllers**
- **Portable Instrumentation**
- **Temperature Acquisition Cards**

GENERAL DESCRIPTION

The ADT70 and ADT71 provide excitation and signal conditioning for resistance-temperature devices (RTDs). They are ideally suited for 1 kΩ Platinum RTDs (PRTDs) allowing a very wide range of temperature measurement. Using a remote, low-cost thin-film, PRTD the ADT70 or ADT71 can measure temperature in the range of –50°C to +500°C. With high-performance platinum elements the temperature change can be extended to 1000°C. Accuracy of the ADT70/ADT71 and PRTD system over a –200°C to +1000°C temperature range depends heavily on the quality of the PRTD. Typically the ADT70/ADT71 will introduce an error of only ±0.1°C over the transducer's temperature range, and the error may be trimmed to zero at a single calibration point.

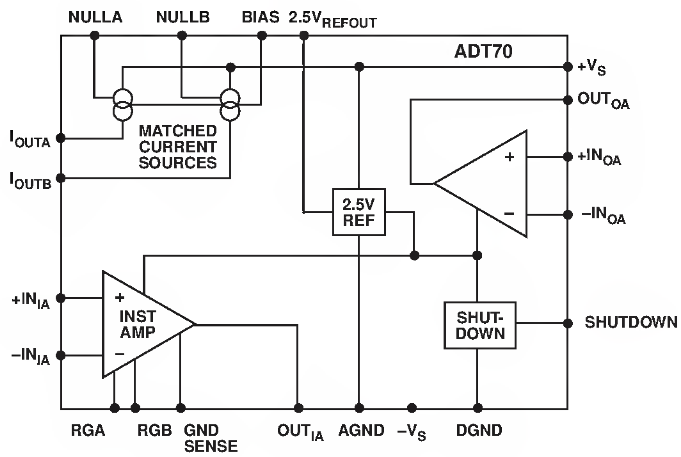
The ADT70 consists of two matched 1 mA (nominal) current sources for transducer and reference resistor excitation, a precision rail-to-rail output instrumentation amplifier, a 2.5 V reference, and an uncommitted rail-to-rail output op amp. The ADT71 is the same as the ADT70 except the internal voltage reference is omitted. The ADT71 is designed for use with either a +4.096 V or +5 V reference. Both devices include a shutdown function for battery powered equipment that reduces the quiescent current from 3 mA to less than 10 µA. The ADT70 and ADT71 operate from either single +5 V or ±5 V supplies. Gain or full-scale range for the PRTD and ADT70/ADT71 system is set by a precision external resistor connected to the instrumentation amplifier. The uncommitted op amp may be used for scaling the internal voltage reference, providing a "PRTD open" signal or "over-temperature" warning, providing a heater switching signal, or other external conditioning determined by the user.

The ADT70 and ADT71 are specified for operation from −40°C to +125°C and are available in 20-pin DIP and SO packages.

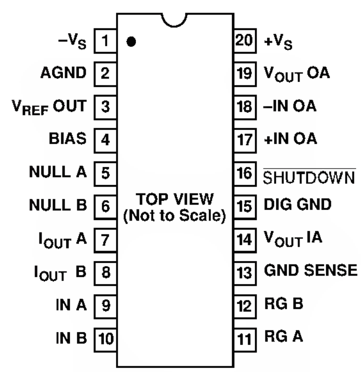
* **Patent pending.**

REV. 0

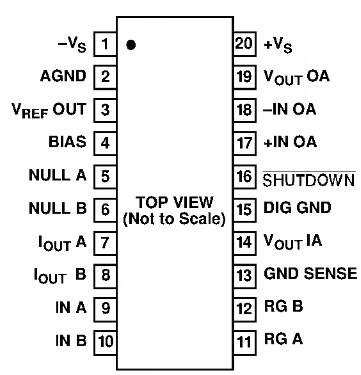
FUNCTIONAL BLOCK DIAGRAM



PACKAGE TYPES AVAILABLE
20-Lead PDIP (P Suffix)



20-Lead SOIC (S Suffix)



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ADT70/ADT71–SPECIFICATIONS (V_S = +5 V, T_A = +25°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
CURRENT SOURCES						
Output Current	I_{Q1}, I_{Q2}	R_L = 1 kΩ		+1.0		mA
Output Current Mismatch	$I_{Q1} – I_{Q2}$	R_L = 1 kΩ		±0.5		µA
Voltage Compliance			$–V_S$		$+V_S$ – 1.5	V
INSTRUMENTATION AMP						
Input Offset Voltage "F" Grade	V_{IOS}				200	µV
Input Offset Voltage "G" Grade	V_{IOS}				500	µV
Output Offset Voltage "F" Grade	V_{OOS}				500	µV
Output Offset Voltage "G" Grade	V_{OOS}				1000	µV
Input Bias Current	I_B					nA
Input Offset Current	I_{OS}					nA
Common-Mode Rejection	CMR					dB
Gain Equation Accuracy "F" Grade						%
Gain Equation Accuracy "G" Grade						%
Output Voltage Swing	V_{OUT}	$R_L = \infty$	$–V_S$ + 10		$+V_S$ – 10	mV
Power Supply Rejection Ratio	PSRR	+ 4.5 V ≤ V_S ≤ +5.5 V				mV/V
VOLTAGE REFERENCE						
Output Voltage				2.5		V
Output Current						mA
Temperature Coefficient				15		ppm/°C
Power Supply Rejection Ratio	PSRR	+ 4.5 V ≤ V_S ≤ +5.5 V				mV/V
OPERATIONAL AMPLIFIER						
Input Offset Voltage	V_{IOA}				500	µV
Input Offset Voltage Drift	ΔV_{IOA}			2		µV/°C
Input Bias Current	I_B					nA
Open-Loop Voltage Gain	A_{VOL}	$R_L = \infty$				V/mV
Output Voltage Swing	V_{OUTA}	$R_L = \infty$	$–V_S$ + 10		$+V_S$ – 10	mV
Common-Mode Rejection Ratio	CMRR					µV/V
Power Supply Rejection Ratio	PSRR	+ 4.5 V ≤ V_S ≤ +5.5 V				µV/V
SHUTDOWN INPUT						
Input Low Voltage	V_{IL}				0.8	V
Input High Voltage	V_{IH}			2.4		V
POWER SUPPLY						
Supply Current	I_{SY}	No Load			3.0	mA
Shutdown Supply Current	I_{SD}				10	µA
Supply Voltage	V_S		+4.5		+5.5	V
Dual Supply Voltage			±4.5		±5.5	V

NOTES

[1]Guaranteed but not tested.

Specifications subject to change without notice.

CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although the ADT70 features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

WAFER TEST LIMITS (V_S = +5 V, GND = 0 V, T_A = +25°C unless otherwise noted)

Parameter	Symbol	Conditions	Min	Typ	Max	Units
POWER SUPPLY						
Supply Current		No Load		3.0		mA

NOTES

Electrical tests are performed as wafer probe to the limits shown. Due to variations in assembly methods and normal yield loss, yield after packaging is not guaranteed for standard product dice. Consult factory to negotiate specifications based on dice lot qualification through sample lot assembly and testing.

[1]Guaranteed but not tested.

Specifications subject to change without notice.

DICE CHARACTERISTICS

Die Size 0.xx × 0.xx inch, xxxx sq. mils
(xx × xx mm, xx sq. mm)
Transistor Count: xx

For additional DICE ordering information, refer to databook.

ABSOLUTE MAXIMUM RATINGS*

Supply Voltage . . . . +16 V
Output Short-Circuit Duration . . . . Indefinite
Storage Temperature Range
P,S Package . . . . −65°C to +150°C
Operating Temperature Range
ADT70/ADT71 . . . . −40°C to +125°C
Junction Temperature Range
P,S Package . . . . −65°C to +125°C
Lead Temperature (Soldering, 60 sec) . . . . +300°C

Package Type	Θ_{JA}[1]	Θ_{JC}	Units
20-Pin SOIC (S)			°C/W
20-Pin PDIP (P)			°C/W

NOTES
[1]Θ_{JA} is specified for device in socket/soldered on circuit board (worst case conditions).

***CAUTION**

1. Stresses above those listed under "Absolute Maximum Ratings" may cause permanent damage to the device. This is a stress rating only and functional operation at or above this specification is not implied. Exposure to the above maximum rating conditions for extended periods may affect device reliability.
2. Digital inputs are protected, however, permanent damage may occur on unprotected units from high-energy electrostatic fields. Keep units in conductive foam or packaging at all times until ready to use. Use proper antistatic handling procedures.
3. Remove power before inserting or removing units from their sockets.
4. Ratings apply to both DICE and packaged parts, unless otherwise noted

ORDERING GUIDE

Model	Temperature Range	Package
ADT70FR	−40°C to +125°C	20-Pin SOIC
ADT70GR	−40°C to +125°C	20-Pin SOIC
ADT71FN	−40°C to +125°C	20-Pin PDIP
ADT71GN	−40°C to +125°C	20-Pin PDIP
ADT70GBC	+25°C	DICE
ADT71GBC	+25°C	DICE

FUNCTIONAL DESCRIPTION

The ADT70/ADT71 provide excitation and signal condition for resistance-temperature devices (RTDs). It is designed to ideally suit for 1 kΩ Platinum RTDs (PRTDs). This allows a much wider range of temperature measurement than silicon-base sensors. Using a low cost PRTD, the ADT70/ADT71 can measure temperature in the range of –50°C to +500°C.

The two main components in the ADT70 are the adjustable current sources and the instrumentation amplifier. The current sources provides the a matching excitation current to the PRTD and the Reference Resistor. The instrumentation amplifier compares the voltage drop across both the PRTD and Reference Resistor, and provides an amplified output signal voltage proportional to temperature.

Besides the matching current sources and the instrumentation amplifier, there is a general purpose Op-Amp for any application desired. Only the ADT70 comes with the +2.5 V reference. The ADT71 is designed to be used with an external +5 V or +4.096 V reference.

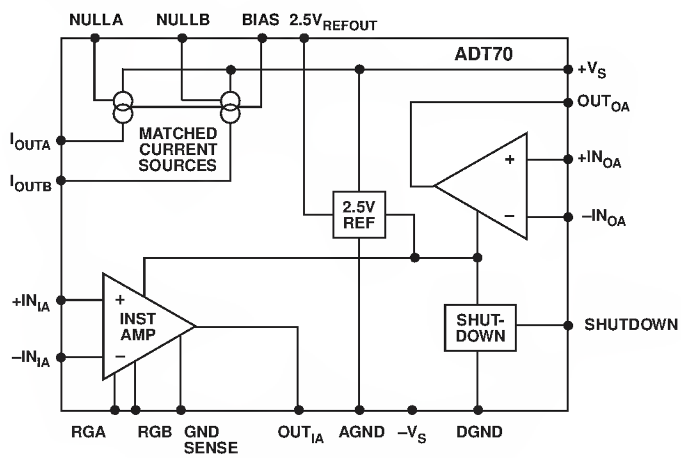


Figure 1. Block Diagram of ADT70

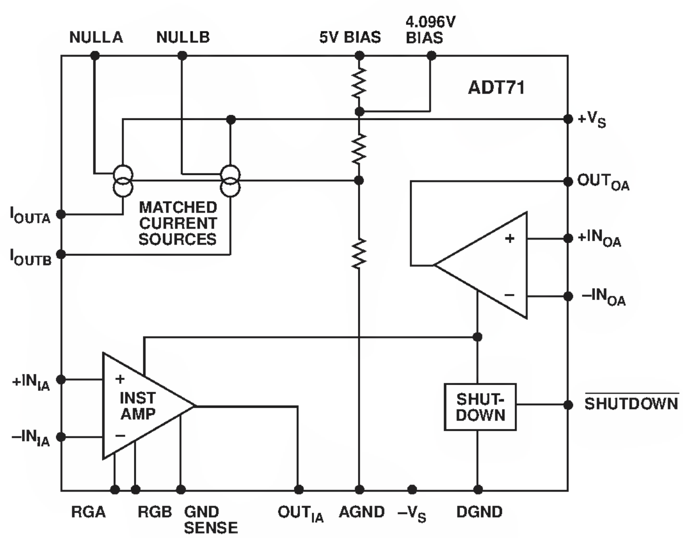


Figure 2. Block Diagram of ADT71

What is an RTD

The measurable temperature range of the ADT70/ADT71 heavily depends on the quality of the resistance-temperature device (RTD). Thus, it is important to choose the right RTD to suit the actual application.

The basic physical property of a metal is that its electrical resistivity changes with temperature. Some metals are known to have very predictable and repeatable change of resistance for a given change in temperature. RTD is a precision resistor which made from one of these metals to a nominal ohmic value at a specified temperature. By measuring its resistance at some unknown temperature and comparing this value to the resistor's nominal value, the change in resistance is determined. Because the temperature vs. Resistance characteristics are also known, the change in temperature from the point initially specified can be calculated. This makes the RTD a practical temperature sensor, which in its bare form is a resistive element.

There are several types of metal which can be used in RTDs. Copper, balco (an iron-nickel alloy), nickel, tungsten, iridium, and platinum are all metals which can be made into RTDs. Platinum is by far the most popular material used, due to its near linearity with temperature, wide temperature operating range, and superior long term stability. The price of Platinum Resistance-Temperature-Device (PRTD) has become more competitive through the wide use of thin film-type resistance elements. This is also one main reason the ADT70/ADT71 is designed to ideally suited for 1 kΩ PRTDs.

Temperature Coefficient of Resistance

The amount of resistance change is called the RTD's temperature coefficient of resistance (TCR) . This is also the alpha value which is commonly denoted by the Greek letter α. It is defined as the change of resistance over 0°C -100ºC divided by the ice point resistance and +100ºC.

$$\alpha = \frac{R_{100} - R_0}{100°C \times R_0}$$

R_0 = Resistance of the sensor at 0ºC

R_{100} = Resistance of the sensor at +100ºC

EQ = Thermal Coefficient of Resistance.

The larger the TCR, the greater the change in resistance for a given change in temperature. The most common use of TCR is to distinguish between curves for platinum, which is available with TCR's ranging from 0.00375 to 0.003927. The highest TCR indicates the highest purity platinum, and is mandated by ITS-90 for standard platinum thermometers.

Basically, all you need to know about TCR is that it must be properly matched when replacing RTD's or connecting them to instruments. There is no technical advantages of one TCR versus another in practical industrial application. 0.00385 platinum is the most popular worldwide standard and is available in both wire-wound and thin-film elements.

Understanding Error Source

The ADT70/ADT71 uses an instrumentation amplifier which amplifies the difference in voltage drop across the RTD and the reference resistor, to output a voltage proportional to the measured temperature. Thus, it is important to use a reference resistor that has stable resistance over temperature. The accuracy of the reference resistor should be determined by the end application.

The lead resistance of wires connecting to the RTD and the reference resistor also could cause inaccuracy to the ADT70/ADT71. If the reference resistor is located close to the part, while the RTD is located at a remote location connected by wires, the lead wires' resistance would contribute to the difference in voltage drop between the RTD and the reference resistor. Thus, an error in reading the actual temperature could occur.

Table I. Wire Gauge Size to Resistance Table.

Lead-wire AWG	Ohms/foot at +25ºC
12	0.0016
14	0.0026
16	0.0041
18	0.0065
20	0.0103
22	0.0162
24	0.0257
26	0.0413
28	0.0651
30	0.1027

From Table I, you can estimate the amount of lead-wire resistance effect in the circuit. For example, assume you connected 100 feet of AWG 22 wire to a 1 kΩ Platinum RTD (PF element). The lead wire resistance will be: R = 100ft × 0.0162 Ω/ft = 1.62 Ω. Thus the total resistance you have with the PRTD will be: R_{total} = 1 kΩ + 1.62 Ω = 1001.62 Ω. Since the 1 kΩ reference resistor is assumed to be relatively close to the ADT70/ADT71, the lead-wire resistance is negligible. This shows 1.62 Ω of inaccuracy.

From the PRTD's data sheet , the PRTD's sensitivity rating (Ω/ºC) can be used with the lead-wire resistance to approximate the accuracy error in temperature degree (ºC). Following the example above, the sensitivity of the 1 kΩ PRTD is 0.385 Ω/ºC (taken from PRTD data sheet). Hence the approximate error is:

$$Error = 1.62\,\Omega / 0.385\,\Omega/°C = 4.21°C$$

assuming the reference resistor is constant at 1 kΩ through out the temperature range.

As shown above, this is a significant inaccuracy, especially for applications where the PRTD would be hundred of feet away from the ADT70/ADT71. In the application circuit section, Figure 4 illustrates how to eliminate such error by utilizing the part's general purpose Op-Amp.

Self-Heating Effect

Another contribution to measuring error is the self-heating affect on the RTD itself. As the RTD element's resistance change due to excitation of current in converting the signal into voltage, this creates power dissipation, and heat which artificially increases the RTD's resistance.

The error contribution of the heat generated can be calculated. For example, if the package thermal resistance is 50ºC/Ω, the RTD nominal resistance is 1 kΩ, and the element is excited with a 1 mA current source, the artificial increase in temperature (ΔºC) as a result of self heating is:

$$\Delta°C = I^2 R_0 \times \theta_{PACKAGE}$$

$$\Delta°C = (1\,mA)^2 \times 1000\,\Omega \times 50°C/W$$

$$\Delta°C = 0.05°C$$

where:

$\theta_{PACKAGE}$ = thermal resistance of package

R_0 = value of RTD resistance

APPLICATION INFORMATION

As shown in Figure 3a and Figure 3b, using a 1 kΩ PRTD, 1 kΩ reference resistor, 50 kΩ resistor between RG_A (Pin 11) and RG_B (Pin 12), and shorting BIAS (Pin4) with $V_{REF\text{-}OUT}$ (Pin 3) together, the output of OUT_{IA} (Pin 14) will have a transfer function of

$$V_{OUT} = 1.30\,mV/\Omega \times \Delta R_{(PRTD\ RESISTANCE - REFERENCE\ RESISTANCE)}.$$

If PRTD has a tempco resistance of 0.00385 Ω/Ω/ºC or sensitivity of 3.85 Ω/ºC, the system output voltage scaling factor will be 5 mV/ºC.

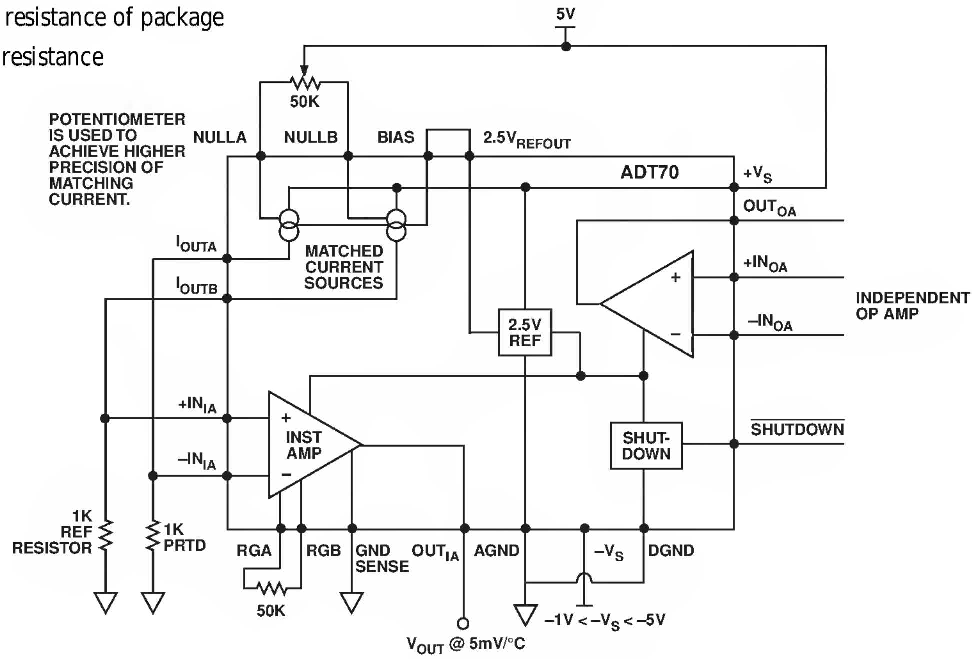


Figure 3a. ADT70 Basic Operational Diagram

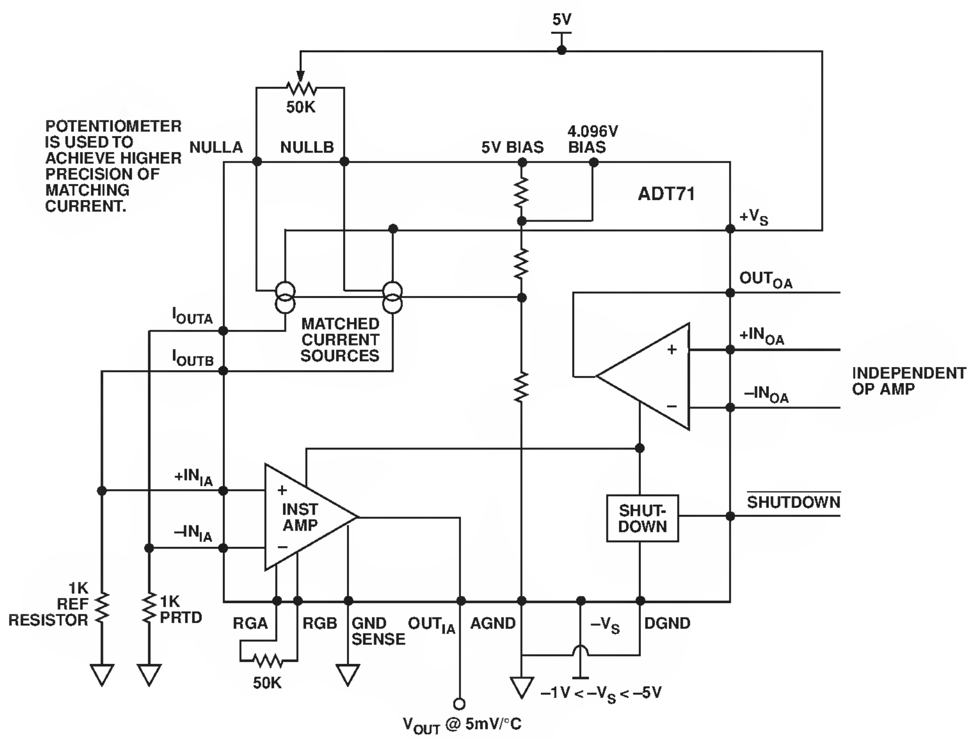


Figure 3b. ADT71 Basic Operational Diagram

The gain of the instrumentation amplifier is normally at 1.66, with a 50 kΩ gain resistor. It can be changed by changing the gain resistor using the following equation.

$$\text{Instrumentation Amp Gain} = 1.66\left(\frac{50\,k\Omega}{R_{GAIN\ RESISTOR}}\right)$$

In Figure 3a and Figure 3b the ADT70/ADT71 is powered by a dual power supply. In order for the part to measure below 0°C, using a 1 kΩ PRTD, $-V_S$ has to be at least –1 V. $-V_S$ can be grounded when the measured temperature is greater than 0°C using a 1 kΩ PRTD. GND Sense (Pin 13), DGND (Pin 15), and AGND (Pin 2) are all connected to ground. If desired, GND Sense could be connected to whatever potential desired for an output offset of the instrumentation amplifier. However, AGND and DGND must always be connected to GND.

ADT70/ADT71 will turn-OFF if the shutdown-pin is low (GND), and will turn-ON when shutdown pin becomes high (+Vs). If shutdown isn't used in the design, it should be connected to +Vs.

The undedicated Op-Amp in the ADT70/ADT71 can be used to transmit measured signal to a remote location where noise might get introduced into the signal as it travels in a noisy environment. It can also be used as a general purpose amplifier in any application desired. The Op-Amp gain is set using standard feedback resistor configurations.

Higher precision of matching the current sources can be achieved by using a 50 kΩ potentiometer connected between NULL A (Pin 5) and NULL B (Pin 6) with the center-tap of the potentiometer connected to +Vs (Pin 20). In Figure 3a, the ADT70's Bias Pin (Pin 4) is generally connected to the V_{REFOUT} (Pin 3), but it can be connected to an external voltage reference if different output current is preferred.

Shown in Figure 3b, the ADT71 is not equipped with an onboard reference. It is designed to be used with an external +5 V or +4.096 V reference. Unlike the ADT70 of having a +2.5 V reference output at Pin 3 and a bias input at Pin 4, the ADT71 has a +5 V and +4.096V bias input at Pin 3, and Pin 4 respectively.

Eliminate Lead-Wire Resistance Using 4-wire configuration

In application where the lead-wire resistance can significantly contribute error to the measured temperature, implementing a 4-wire lead-resistance canceling circuit can minimize the lead-wire resistance effect dramatically.

In Figure 4, I_{OUTA} and I_{OUTB} provides matching excitation to the reference resistor and the PRTD respectively. The lead-resistance from the current source to the PRTD or reference resistor is not in concern because the instrumentation amplifier is measuring the difference in potential directly on the PRTD (Node-A) and reference resistor (Node-C). Since there is no current going from Node-A and Node-C into the amplifier's input, there is no lead-wire resistance effect.

To cancel the lead-wire resistance from the Node-B to GND, the Op-Amp's positive input is connected directly to Node-B, making sure the reference resistor is also having the same potential at Node-D.

It is not very crucial to make Node B and D to be zero potential, because as long as they are the same potential as GND-Sense of the instrumentation amplifier, the output would naturally compensate this effect to provide a more accurate measurement of the temperature.

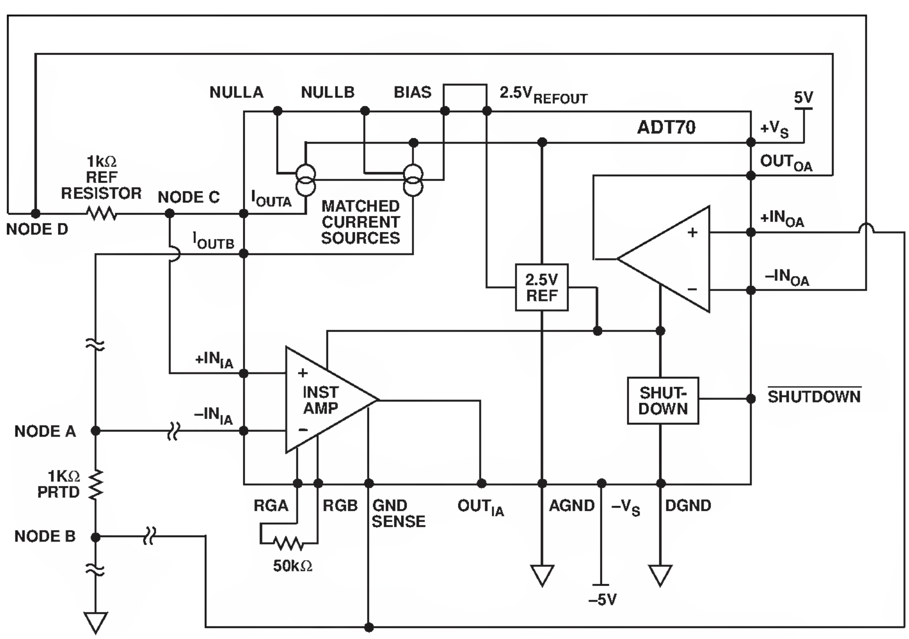
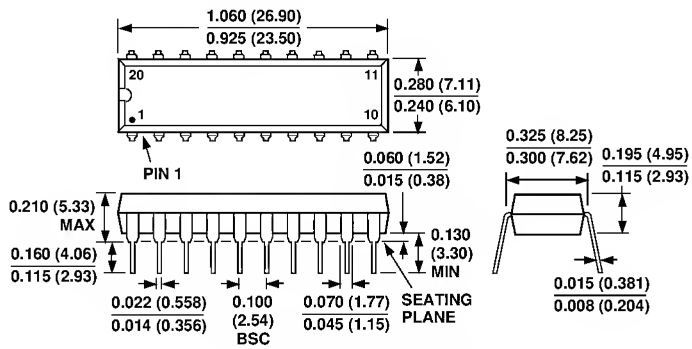


Figure 4. 4-wire Lead-Wire Resistance Cancellation Circuit

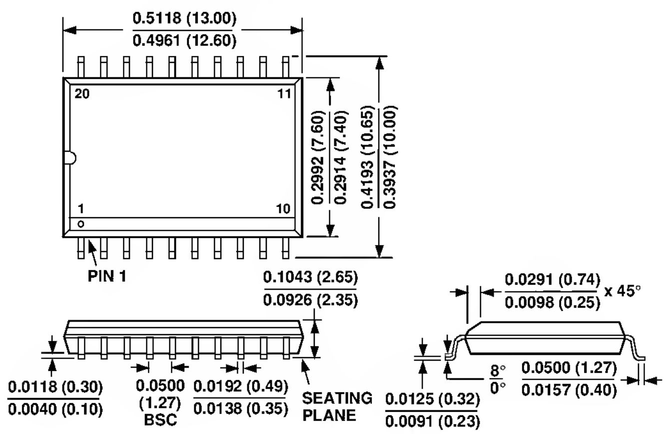
OUTLINE DIMENSIONS

Dimensions shown in inches and (mm).

20-Pin Plastic DIP (P-Suffix)



20-Lead SOIC (S-Suffix)



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